Proceedings of the 4th World Congress on Mechanical, Chemical, and Material Engineering (MCM'18)
Madrid, Spain – August 16 – 18, 2018
Paper No. HTFF 105
DOI: 10.11159/htff18.105

Thermally Uniform Powder Bed for Laser Sintering

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Abstract - Modern manufacturing processes have extremely miniscule tolerances, a common process being that of thermal uniformity. Uniformly heated instrumentation systems are generally expensive, inefficient, unpredictable, large and bulky. Current manufacturing methods require increasingly demanding accuracy and precision. Engineers rely on these technologies to move cutting edge development forward. Any improvement in facilitating these processes can have immediate and wide-ranging impact. Some of these manufacturing processes require thermally narrow process windows. These include powder bed fusion, thermoforming, solder re-flow, and resin curing. The current solutions are extremely large and expensive. The need is for a smaller format, cost efficient solution to these manufacturing problems and processes so that they can be easily purchased for small companies, educational facilities, as well as at home use.
The objective of this research is to build a sub-system that creates a thermally stable and uniform bed temperature which can be used for many applications and to explore different ways to test the design and analyse the data.

***Keywords*: ** Bed Fusion, Thermoforming, Resin, Solder Re-Flow.

1. Introduction

Estimation of the temperature field in the powder bed in selective laser sintering process is a key issue for understanding the sintering/binding mechanisms and for optimizing the technique. Heat transfer may be strongly affected by formation and growth of necks between particles due to sintering when the contact conductivity becomes predominant in the powder bed effective thermal conductivity. The necks often remain small as compared to the particle size. To calculate the effective contact conductivity of such structures a model of independent small thermal contacts is proposed. The conductivity of the considered cubic-symmetry lattices and the random packing of equal spheres depends on the three structural parameters: the relative density, the coordination number, and the contact size. The present model agrees with the known numerical calculations in the range of contact radius to particle radius ratio below 0.3. The strong dependence on the contact size is qualitatively confirmed by experimental data. [1]. Layered manufacturing (LM) is gaining ground for manufacturing prototypes (RP), tools (RT) and functional end products (RM). Laser and powder bed based manufacturing (i.e. selective laser sintering/melting or its variants) holds a special place within the variety of LM processes: no other LM techniques allow processing polymers, metals, ceramics as well as many types of composites. To do so, however, quite some different powder consolidation mechanisms are invoked: solid state sintering, liquid phase sintering, partial melting, full melting, chemical binding, etc. The paper describes which type of laser-induced consolidation can be applied to what type of material. It tries to understand the underlying physical mechanisms and the interaction with the material properties. The paper demonstrates that, although SLS/SLM can process polymers, metals, ceramics and composites, quite some limitations and problems cause the palette of applicable materials still to be limited. There is still a long way to go in tuning the processes and materials in order to enlarge the applicability of LM. This is not surprising if one compares it to the decades of R&D work devoted to tuning processes and materials for hot or cold forming, metal cutting (e.g. development of free machining steels), casting and injection molding (including powder injection molding: MIM, CIM, etc.) [2]. the effect of powder bed temperature setting on the prediction of density of sintered parts produced by the selective laser sintering (SLS) process is reported. A crystalline polymer, nylon-12 – commercially named Duraform polyamide – has been used in this work. To study the effect of the powder bed temperature, a two-dimensional model of the sintering process for crystalline polymers has been developed. Latent heat has been considered in the model. Three powder bed temperature settings, 174, 178 and 182○C, have been applied to study their effect on the sintered parts' density and size accuracy. This paper only reports on density. Results show that at a powder bed temperature of 182○C, a fully solid density, 970kg/m3, can be obtained at a default energy density of 0.0284J/mm2. By reducing powder bed temperature to 178○C, at the same energy density, density of a sintered part decreases by about 4 per cent. M. Matsumoto et al. [4] showed A method for calculating the distribution of temperature and stress within a single metallic layer formed on the powder bed in rapid prototyping with the selective laser melting method is proposed. The solidified layer is assumed to be subjected to plane-stress deformation and the two-dimensional finite element methods for heat conduction and elastic deformation are combined. In the simulation, the finite element mesh is constructed on the surface of the powder bed. The heat caused by laser irradiation is given to the elements under the laser beam. Shrinkage due to solidification is assumed to result in only the change of the layer thickness. In the elastic finite element simulation, the Young's modulus of the solidified part is expressed as a function of temperature. To simplify the calculation, the whole area is treated to be continuous, and the powder bed and the molten part are assumed to have a very small Young's modulus. The heat conduction and the elastic finite element calculations are carried out alternately. The obtained results of deformation and tensile stress distribution show the possibility and places of cracking of the layer during forming. J.-P.Kruth et. al. showed that the Layered manufacturing (LM) is gaining ground for manufacturing prototypes (RP), tools (RT) and functional end products (RM). Laser and powder bed based manufacturing (i.e. selective laser sintering/melting or its variants) holds a special place within the variety of LM processes: no other LM techniques allow processing polymers, metals, ceramics as well as many types of composites [5].

The objective of this project is to build a sub-system that creates a thermally stable and uniform bed temperature which can be used for many applications.

2. Design and Analysis

Different geometries of the oven were studied and analysed. However, the cubic enclosure analysis was chosen as an initial solution. It can also apply to different heater locations, for example the heaters can be placed at the top or sides of the cube and the analysis will remain the same. This is because the analysis of the cube is mainly looking at how the temperature varies as a function of the height of the cube. This gave the team an opportunity to vary the height and see if less material could be used and the same temperature would be produced. As shown in the below figure 1, a diagram of the cube is presented with the governing equations and finite element analysis. SOLIDWORKS Simulation uses the displacement formulation of the finite element method to calculate component displacements, strains, and stresses under internal and external loads. The geometry under analysis is discretized using tetrahedral (3D), and solved by iterative solver. SOLIDWORKS Simulation using p adaptive element type, the solution has converged. The material parameters were obtained and the results were simulated. One of the most important inputs to the model is the elastic modulus E of the material. The elastic modulus defines the stiffness (resistance to deflection) of the material. Its value is determined from material tests. A material with a high value of E will deflect less than one with a lower value of E. By applying finite element analysis, we can accurately observe the stress distributions in the various layers of the material as shown in Figures 1. The highest stress is 4039 psi with mesh size was 0.2. However, the maximum deflection was 0.7 inches.

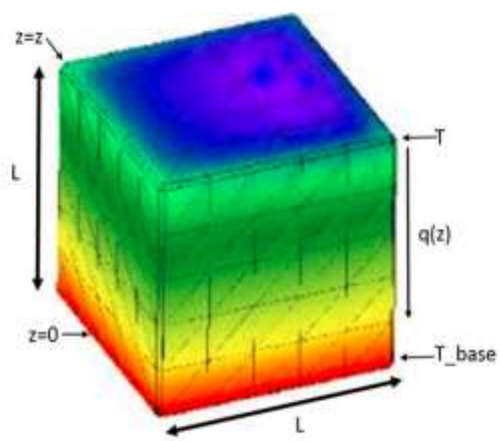

Fig. 1: a diagram of the cube.

Governing Equation:

$$\frac{(q_{dot})A}{\pi c^2}\left(-\frac{1}{z}\right) = -k(T - T_{base}) \tag{1}$$

Temperature as a function of height

$$T(z) = \frac{(q\_dot)A}{zk\pi c^2} + T_{base} \tag{2}$$

3. Material and Experiments Procedure

The first steps in building the prototype was of course ordering all of the raw materials. Next, we cut the 80/20 aluminum frame to the proper lengths in order to build the frame of the oven.

We assembled the individual pieces together with brackets also bought from the 80/20 manufacturer that held the frame together perfectly. Next, the fiber glass insulation into the correct sizes to fit snuggle just inside of the aluminum frame. We then cut steel into the correct sizes to adhere it onto the inside of the fiberglass insulation to create the interior walls of the oven. We sealed all of the corners and interior edges with RTV or Room Temperature Vulcanization adhesive, which is a silicone adhesive. Once those steps were complete, we moved onto cutting the proper holes in the side of the insulation and steel for the wired, fan attachment and interrogation window. We crafted up some homemade steel brackets to hold the IR heaters in place, as well as to attach them magnetically to the ceiling of the oven. We fasted the IR ceramic heaters to the brackets, and attached those to the ceiling using strong heat resistant magnets, which will later on aid in the ease of manipulating heater placement and number. We threaded the heater wires through the holes previously cut out in the sides. We attached the fan and motor to the back of the oven as shown in figure 2, a and b. table 1 shows the material and the components were used to build the powder bed.

(a) (b)

Fig. 2: Final prototype: a- the internal of the oven, b- the external of the oven.

Table 1: Oven materials and components.

Components
8020 T-Slotted Framing
8020 Internal Brackets
8020 Panel Brackets
Exterior Panels
Internal Heater Brackets
Thermocouple Probes for Surface
Ceramic IR Heater Elements
IR Thermometer
Oven Fan
Materials
Rigid Fiberglass Insulation
Steel Sheets, 0.03"
BK7 Glass, 3mm
Supplies
High-Temperature Silicone Sealant
Aluminum Tape

3. Results

Figure 3 below shows the best temperature distribution we could achieve. The darker areas represent the metal surround to the powder tray. As you can see the temperature was within plus or minus two degrees.

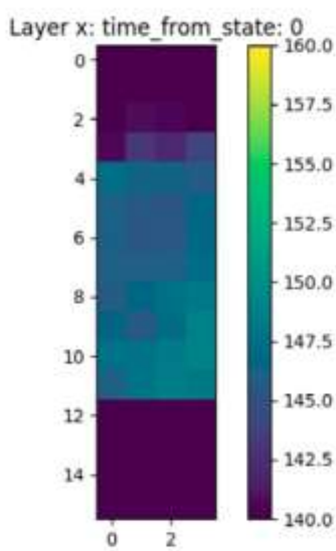

Fig. 3: heat-map of powder bed.

An Infra-Red camera is used which is returning 16-bit images, an image stored as an I16 is using an integer value to represent each pixel value. To retain maximum accuracy we first cast the image into a format that supports floating point representation of the pixels. We did this using the IMAQ Cast Image function and cast the image to SGL type. This represents pixels with a floating point value so when we scaled the image it will retain maximum accuracy.

Figure 4 shows that the temperature of each pixel is increasing with the time, after 98 seconds the changes in temperature values of each pixel with the time are insignificant and the difference in the temperature of each pixel is two to three degrees.

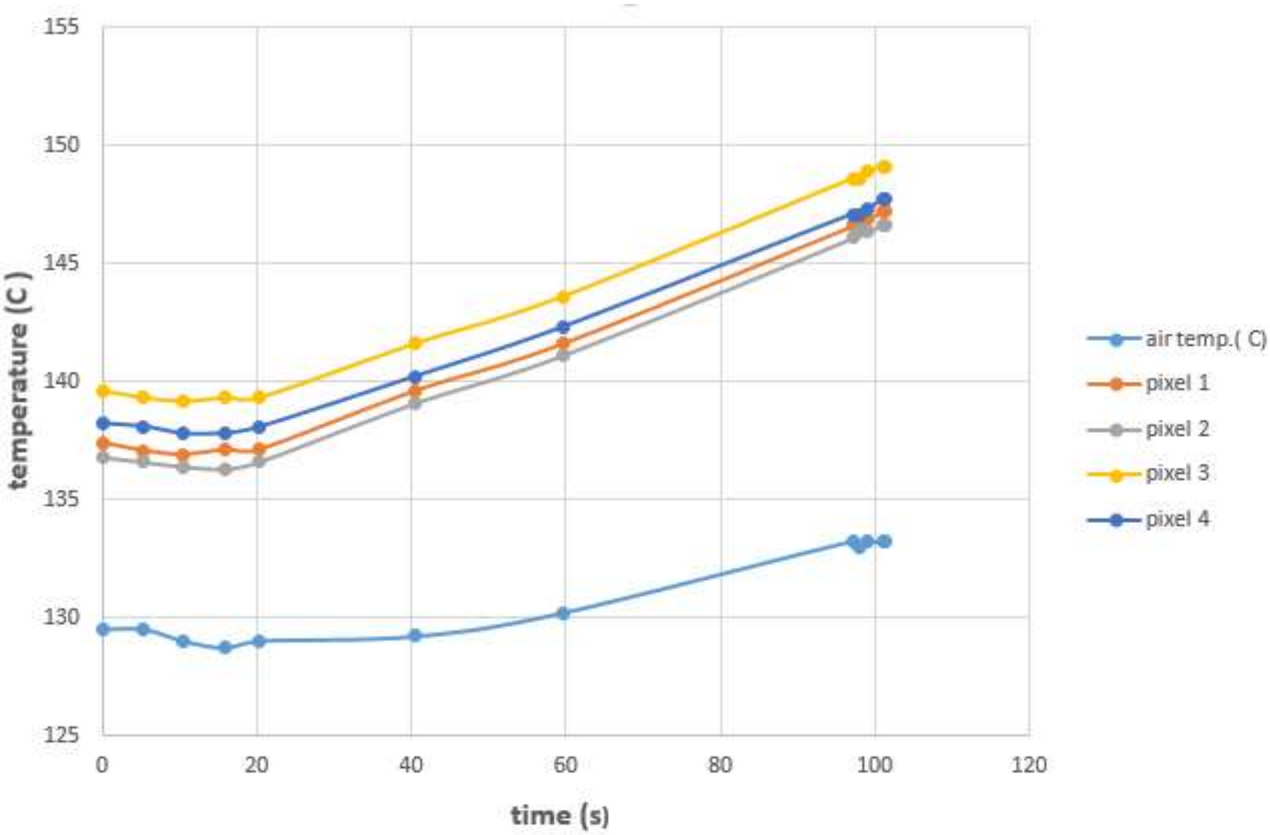

Fig. 4: time vs temperature.

4. Conclusion

Estimation of the temperature field in the powder bed in selective laser sintering process is a key issue for understanding the sintering/binding mechanisms and for optimizing the technique. Heat transfer may be strongly affected by formation and growth of necks between particles due to sintering when the contact conductivity becomes predominant in the powder bed effective thermal conductivity. The prototype showed little difference in uniformity based on heater angle or distance. Forced convection was necessary for thermal uniformity. Controlling all the heaters identically driven off an average of the center 16 pixels gave us the best results. The data shows that we were able to achieve our goal of staying plus or minus three degrees across the area of the tray.

Nomenclature

T: temperature
qdot: heat transfer rate (Watt)
A: area
k: thermal conductivity

References

[1] A.V. Gusarov, T. Laoui, L. Froyen, V.I. Titov, "Contact thermal conductivity of a powder bed in selective laser sintering," *International Journal of Heat and Mass Transfer*, vol. 46, pp. 1103-1109, 2003.

[2] J. P. Kruth, G. Levy, F. Klocke, and T. H. C. Childs, "Consolidation phenomena in laser and powder-bed based layered manufacturing," *CIRP Annals - Manufacturing Technology*, vol. 56, no. 2, pp. 730-759, 2007.

[3] A. E. Tontowi, and T. H. C. Childs, "Density prediction of crystalline polymer sintered parts at various powder bed temperatures," *Rapid Prototyping Journal*, ISSN: 1355-2546, 1995.

[4] M. Matsumoto, M. Shiomi, K. Osakada and F. Abe, "Finite element analysis of single layer forming on metallic powder bed in rapid prototyping by selective laser processing," *International Journal of Machine Tools and Manufacture*, vol. 42, no. 1, pp. 61-67, 2002.

[5] J.-P.Kruth, G. Levy, F. Klocke, T. H. C.Childs, "Consolidation phenomena in laser and powder-bed based layered manufacturing," *CIRP Annals*, vol. 56, no. 2, pp. 730-759, 2007.